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Energy performance of historical brick buildings in Northern Climate zone

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Abstract

Historic buildings are considered to be one of the precious gems of Europe, which defines its character and rich cultural heritage. Therefore historical buildings with historical significance must be valued and preserved. The climate conditions to which buildings are subjected may deteriorate their structural elements therefore reducing their life span. As there are several types of historic building structural elements, there are also several types of possible solutions for historical building structural element protection from further deterioration. Also there is a necessity to assess current heat energy consumption in historical buildings to develop each specific case tailored energy efficiency improvement and facade protection measures. Therefore there is a necessity for historical building typology development, to distinguish different historical building structural elements with similar properties which may have similar measures for building envelope protection and heat energy reduction. This research focuses on historic brick building heat energy consumption analysis to define benchmarks and to analyse the influence of various different building material characteristics on historic building heat energy consumption.

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Keywords: historic buildings; energy efficiency indicators; building typology; cultural heritage

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1. Introduction

Historic buildings are reflections of many European cities and they are a tribute to Europe's rich cultural heritage. Historical building energy performance is dependent on a delicate balance between energy efficiency measures and the necessity to preserve the appearance of the building which represents its cultural heritage value. [1]

European building stock accounts for about 25 billion m^2 of conditioned space of which a significant portion is be considered to be old building stock, of which about 40 % are built between 1960 and 1945, 26 % between 1945 and 1919 and 14 % are built earlier than 1919 [1, 2]. Although the total number of old and historical building stock in Europe is uncertain and is not specifically defined, around 10 % of the buildings are assumed to have preservation value and about 2 % of these buildings can be considered historical [4−6]. Only a certain amount of historical buildings are considered to pose significant cultural heritage value, which imposes the necessity to treat them with care to preserve their cultural and architectural values. Many of these buildings have building envelopes with insignificant thermal performance, which causes high energy demand for space heating and, in a majority of cases, also insufficient thermal comfort for their inhabitants. Restoration and maintenance works must be carried out with extra care in order to preserve the integrity and uniqueness of the historical buildings' structures, therefore historical buildings should not be subjected to strict requirements regarding thermal performance of building envelope implemented into national legislation, rather on realistic energy performance measures, that initially are based on the need to preserve cultural heritage values. The total amount of buildings possessing significant cultural heritage value is relatively small, therefore the suggested lower requirements towards historic building envelope elements do not contrast with overall EU goals regarding building energy use [4, 7, 8]. Decisions on the necessity to perform building retrofit projects must be linked to local governmental and municipal strategies, therefore local decision makers need to be aware of possible variations and restrictions regarding historical building preservation and energy efficiency improvements [1, 3].

From the building physics perspective, exterior insulation is preferred to internal insulation. Exterior building component insulation provides protection of exterior building elements which otherwise are subjected to the negative influence of environmental factors. Exterior insulation prevents building exterior elements to be subjected to temperature levels below freezing point and reduces the negative influences caused by thermal bridges. When considering internal insulation of historical building envelope elements, it is also necessary to assess suitable methods of exterior element treatment with protection layers to hinder potential damage caused by external environment influence. [8] Average heat energy consumption for heating wood-framed buildings in cold climate countries differs due to various factors and location (consumption in detached and semi-detached houses in Greenland − 416 kWh/(m^2a), Norway − 181 kWh/(m^2a), Canada − 231 kWh/(m^2a), Greenland − 383 kWh/(m^2a)). Heat consumption for a typical brick building in a cold climate varies from 170 kWh/(m^2a) to 280 kWh/(m^2a). These values are close to the results of Eastern European countries [9].

It is extremely challenging to increase energy efficiency levels in buildings with significant cultural heritage value. These buildings are protected by law which implies that significant restrictions regarding the possibilities of historical building envelope retrofit are valid.

The most efficient building retrofit measure, which potentially can contribute to highest energy consumption reduction, is by insulating outer walls and changing windows. The change of windows in historical buildings is generally allowed, if all the requirements regarding the integrity of historical value is preserved, however, exterior wall insulation from the outside is prohibited. Therefore it is necessary to examine the energy efficiency state of historic buildings in Northern climatic region and develop appropriate classification of historical buildings to represent the possible energy efficiency level of each historical building group. Some research has been done to determine the energy efficiency levels and energy efficiency potential with different measures in historical buildings outside Latvia. Fabrizio Ascione et.al. [1] have done extensive research to investigate energy retrofit possibilities of historical buildings in Italy. This study suggests to use thermal plaster as an insulation material. Said M.N.A et. al. [2] have investigated how internal wall insulation affects hygrothermal performance of a masonry wall. E. Grinzato et.al.[4] have used thermography to investigate the historical building envelope. The developed methodology gives the possibility to assess the moisture and thermal diffusivity of walls in historical buildings. The existing energy efficiency level in historical buildings has been investigated in research of Kristian Fabbri et.al. [5], where Energy performance certificates were used to classify historical buildings by their energy consumption, but no extensive research has been done to determine factors influencing each building groups energy consumption and appropriate energy efficiency levels.

2. Methods

To determine existing energy efficiency and energy consumption in historic brick buildings, it is possible to use either measured or calculated heat energy consumption data. In this research, an analysis of heat energy consumption in historical brick buildings is done, by gathering measured energy consumption data instead of calculating the required data. Only buildings connected to the district heating system can provide reliable measured energy consumption data. During the research measured data for 171 historical brick buildings were collected from AS “Rīgas siltums” [10], the only district heating provider in Riga. For each building the following information was gathered:

- Address of the building (not disclosed in this paper);
- Heated area of the building;
- Year of construction;
- Monthly total heat energy consumption data from October 2009 till September 2012;
- Beginning and ending of heating seasons in the period for which energy consumption data are available;
- Daily outdoor air temperatures in Riga for the period for which energy consumption data are available.

Historic buildings in the central part of Riga, where the highest concentration of historical brick buildings can be found, were chosen for analysis. All of these buildings have been built between 1850 and 1940. The building construction year and amount of buildings built in the corresponding period can be seen in the histogram shown in Fig.1.

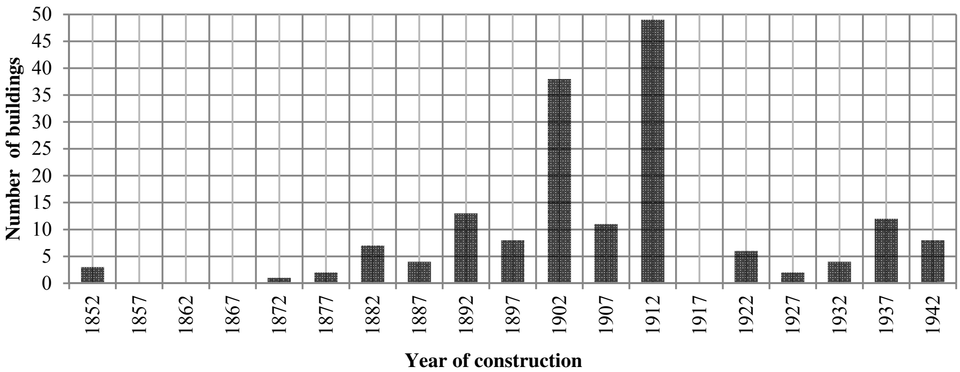

Fig.1. Histogram of building construction years of 171 buildings analysed.

It can be seen that most of the analysed buildings were built from 1900 till 1915. Heated areas of the buildings depending on the building construction year are shown in Fig.2, where it can be seen that the heated areas of analysed buildings are in a wide range.

Total heat energy consumption consists of energy for space heating and energy used for hot water preparation. Some of the buildings use energy from the district heating company only for space heating and hot water is prepared by wood log, gas boilers or electric water heaters. Data on space heating were analysed for all 171 buildings, but data on hot water heat consumption were analysed only in those buildings, where hot water was prepared via the district heat energy supplier. In total there were 132 buildings in which hot water is prepared with heat energy from the district heating system.

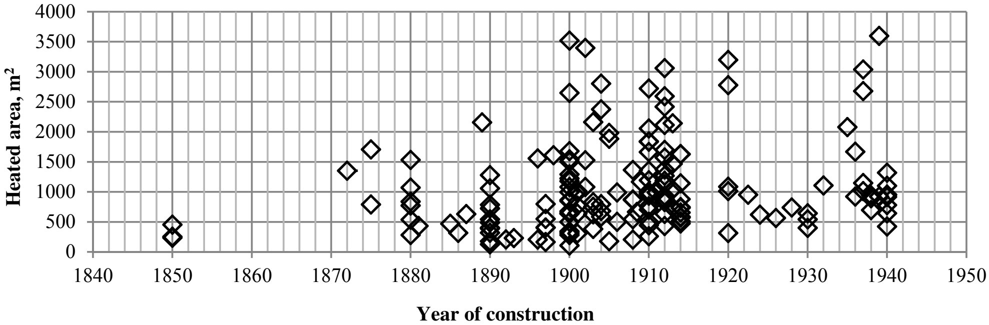

Fig.2. Heated area of the analysed buildings depending on the building construction year.

In these buildings, energy consumption for space heating and hot water preparation is usually measured with one heat meter, therefore calculation (1) was done to allocate space heating from heat consumption for hot water preparation. The average heat energy consumption of a building in five months outside the heating season (from May till September) was assumed to be the average monthly heat energy consumption for hot water preparation.

$$Q_{hot\_water} = \frac{\sum_{i=may}^{september} Q_{total}}{5} \cdot 12, \tag{1}$$

where
Q_{hot_water} – heat energy necessary for hot water preparation, MWh/year;
Q_{total} – consumed heat energy in building according to heat meter in respective month, MWh/month.

Yearly heat energy consumption for hot water preparation was calculated by multiplying average monthly heat energy consumption by 12 months (the length of year). Space heating energy consumption was calculated (2) as the difference between total heat energy consumption and heat energy consumption for hot water preparation.

$$Q_{space\_heat} = \sum_{i=january}^{december} Q_{total} - Q_{hot\ water}, \tag{2}$$

where
Q_{space_heat} – heat energy consumption for space heating, MWh/year.

Since each heating season has a different length and average outdoor air temperature, climate correction was done to obtain comparable data. All space heating energy consumption data were recalculated to a 203-day long heating season with the average outdoor air temperature of 0 °C, which corresponds to the normative heating season in Riga [13]. Climate correction was done according to standard approved in Latvian legislation [12].

Since absolute heat energy consumption does not show the energy efficiency level of the building only specific heat consumptions in kWh/m^2 per year were analyzed.

3. Results

The average climate corrected energy consumption for space heating in the 171 buildings analysed in heating seasons from 2009 till 2012 is 181 MWh per year. Since there are larger and smaller buildings, the average weighted energy consumption was also calculated. The average weighted energy consumption more objectively describes energy consumption. The average weighted climate corrected energy consumption for space heating in the 171 buildings analysed in last three heating seasons is 161 kWh/m^2 per year. The average heat energy consumption for hot water preparation in analysed buildings for the last two years is 34 kWh/m^2 per year. In comparison, the average energy consumption in Latvia is 235 kWh/m^2 per year (180 kWh/m^2 per year for space heating and 55 kWh/m^2 per year for hot water preparation) [13].

The specific heat energy consumption for space heating for each building depending on its year of construction and heated area can be seen in Fig.3. and Fig.4.

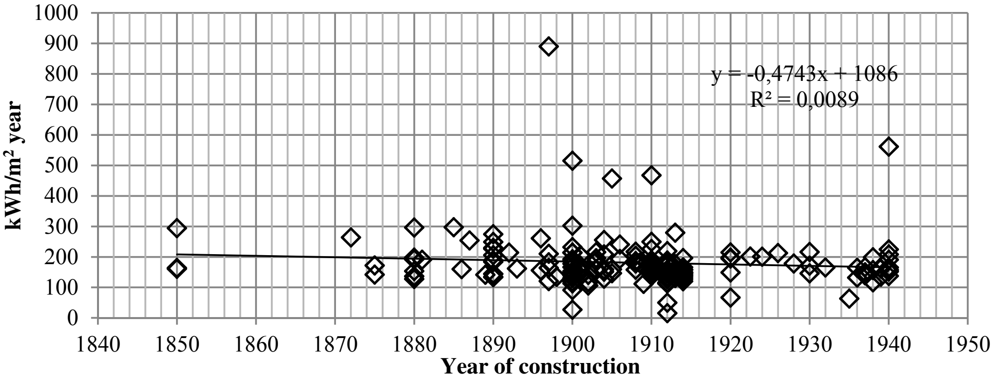

Fig.3. Energy consumption for space heating depending on different building construction year.

As can be seen from both figures, specific energy consumption for space heating is not influenced neither by the construction year of the building nor by the heated area of the building. There is a slight decrease in energy consumption for younger and larger buildings, but the correlation of data is very weak.

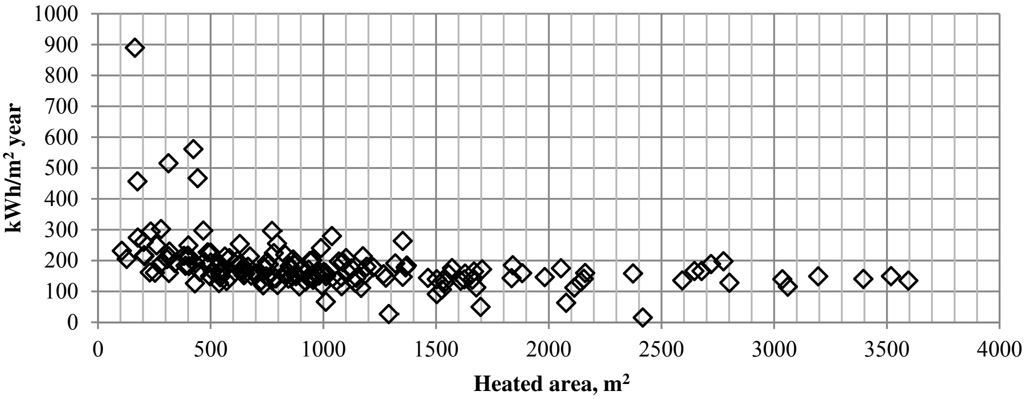

Fig. 4. Specific energy consumption for space heating for different heated areas.

If a large data set (specific energy consumption in historical buildings) is analyzed, the standard deviation (σ) of this data set allows to make assumptions about the whole population (specific energy consumption in all historical buildings in Riga). Standard deviation of specific space heating consumption in 171 historical buildings is 87 kWh/m^2 per year, which means that 68.2 % of historical buildings consume between 94 and 268 kWh/m^2 per year for space heating. During the data analysis procedure it was determined that 15 out of 171 buildings are outside the 2σ limit, which means that these data are suspicious, in this case it could happen because some buildings are only partly heated by district heating and for some buildings incorrect data were provided either for heat energy consumption or heated area. Since there was no possibility to check these data, the median of the analysed data was calculated instead of the average or average weighted heat energy consumption. Calculating the median gives the possibility to disregard the suspicious energy consumption data. The median is found by arranging all the building energy consumption data from lowest to highest value and picking the middle figure. Median for a data set usually is calculated if there are big differences between average and extreme values. Median space heating energy consumption, which in this case best describes average energy consumption in historical buildings, for all 171 buildings is 166 kWh/m^2 per year, but for hot water preparation it is 31 kWh/m^2 per year.

By doing energy consumption data analysis in historical brick buildings, it was determined that median energy consumption should be used to describe the average energy consumption in these type of buildings. Energy consumption for space heating in the analysed historical buildings is 166 kWh/m^2 per year and 31 kWh/m^2 per year for hot water preparation, which is lower than the average energy consumption in Latvia. The authors suspect that this can be explained by the following facts:

- Average heat energy consumption in Latvia is quite high, [13] because a major part of buildings were built during the Soviet times when energy efficiency standards were very low;
- Historical brick buildings have thicker walls than in the average building in Latvia;
- Indoor air temperatures in historical buildings quite often are kept lower than in average buildings in Latvia.

Heat energy consumption in historical buildings is not greatly affected by the heated area or the building year of construction. The reason for this has to be investigated in further research.

4. Discussions

Even though heat energy consumption in historical brick buildings is lower than average value in Latvia, it is still considered to be very high if compared to new buildings and existing energy efficiency requirements. Therefore there is need for research on energy efficiency measures for historical brick buildings that allow reaching lower heat energy consumption for space heating, but at the same time do not decrease the historical value of these buildings. There is a need for further investigation on existing energy efficiency of the historical buildings, as part of these buildings are still heated by individual wood log or gas boilers, which can greatly influence the energy consumption data quality in these buildings. There is a need for a new legislative framework on energy efficiency in historical buildings because new techniques and materials for increasing energy efficiency have been developed in the last years.

Acknowledgements

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